NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 339

FULL SCALE WIND TUNNEL TESTS WITH A SERIES OF PROPELLERS OF DIFFERENT DIAMETERS ON A SINGLE FUSELAGE

By FRED E. WEICK

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp
Speed		km/hr	k. p. h.	mi./hr.	m. p. h.
		m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from C. G. to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/s, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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Langley Memorial Aeronautical Laboratory

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL REPORT NO. 339.

FULL SCALE WIND TUNNEL TESTS WITH A SERIES OF

PROPELLERS OF DIFFERENT DIAMETERS ON A SINGLE FUSELAGE.

Page 3, column 1, line 9 from top:

Page 11, column 1, line 6 from bottom:

Page 11, column 2, last line:

Change "1 per cent for a 10 per cent" to read

"1 per cent for a 5 per cent"

REPORT No. 339

FULL SCALE WIND TUNNEL TESTS WITH A SERIES OF PROPELLERS OF DIFFERENT DIAMETERS ON A SINGLE FUSELAGE

By Fred E. Weick

SUMMARY

Aerodynamic tests were made with four geometrically similar metal propellers of different diameters, on a Wright "Whirlwind" J–5 engine in an open cockpit fuselage. The tests were made in the Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. The results show little difference in the characteristics of the various propellers, the only one of any importance being an increase of efficiency of the order of 1 per cent for a 10 per cent increase of diameter, within the range of the tests.

INTRODUCTION

This investigation was made in order to obtain practical information regarding one phase of the problem of the mutual interference between aircraft propellers and the bodies on which they are mounted, i. e., the effect of the size of the propeller with respect to the body.

Many model tests have been made involving propeller-body interference but in nearly all cases idealized bodies of simple shape have been used, and so, while the results are interesting in that they indicate general tendencies, they have little quantitative value when applied directly to actual aircraft. In the present tests a full-sized open cockpit fuselage with a 200 horsepower radial air-cooled engine was used along with four metal propellers varying in diameter from 8 feet 11 inches to 10 feet 5 inches. The results are therefore considered directly applicable to aircraft conditions in which similar bodies and propellers are used.

The tests were made in the Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics.

APPARATUS

The propeller blades and hub used in this investigation were furnished by the Navy Department. The blades were made of aluminum alloy, according to the drawings in Figures 1, 2, 3, and 4. The blades were all geometrically similar except that they were all made to fit the same hub. They were all set at a blade angle of 15.5° at 75 per cent of the tip radius. The blade width and thickness ratios and also the pitch ratios are plotted against radius in Figure 5. In order to save weight, the steel hub, which was used for all of the blades, had been made 1 inch shorter than the hub for which the blades were designed. Therefore, while the drawings show diameters of even 9 feet, 9 feet 6 inches, 10 feet, and 10 feet 6 inches, the actual diameters were 8 feet 11 inches, 9 feet 5 inches, 9 feet 11 inches, and 10 feet 5 inches.

The Propeller Research Tunnel is of the open-jet type, with an air stream 20 feet in diameter in which velocities up to 110 miles per hour can be obtained. A description of the tunnel, balances, and other measuring devices is given in reference 1.

The propellers were tested on a conventionally cowled 200 horsepower Wright J–5 radial air-cooled engine which was mounted in an open cockpit fuselage, as shown in Figures 6 and 7. The maximum cross-sectional area of the fuselage was approximately 11 square feet.

The J–5 engine was mounted on a dynamometer within the fuselage so that the engine torque could be measured directly.

METHODS

The engine torque as measured included the torque on the engine cylinders due to the twist of the slip stream. In order to correct for this effect a special test was made in which three J–5 cylinders complete with valve gear were mounted under the front portion of a water-cooled Wright E–2 engine on a VE–7 fuselage in the Propeller Research Tunnel. (Figure 8.) The cylinders were in the same position relative to the propeller as on a J–5 engine. The middle cylinder only was supported in such a manner that the torque on it about the engine axis could be measured, and the 8-foot 11-inch propeller of the present tests was driven by the E–2 engine. The torque due to the twisting slip stream was then found for various engine and air speeds. The results have been used to apply a correction, amounting to as much as 3 per cent in some cases, to the measured engine torque, due allowance being made for the greater size of the other propellers.

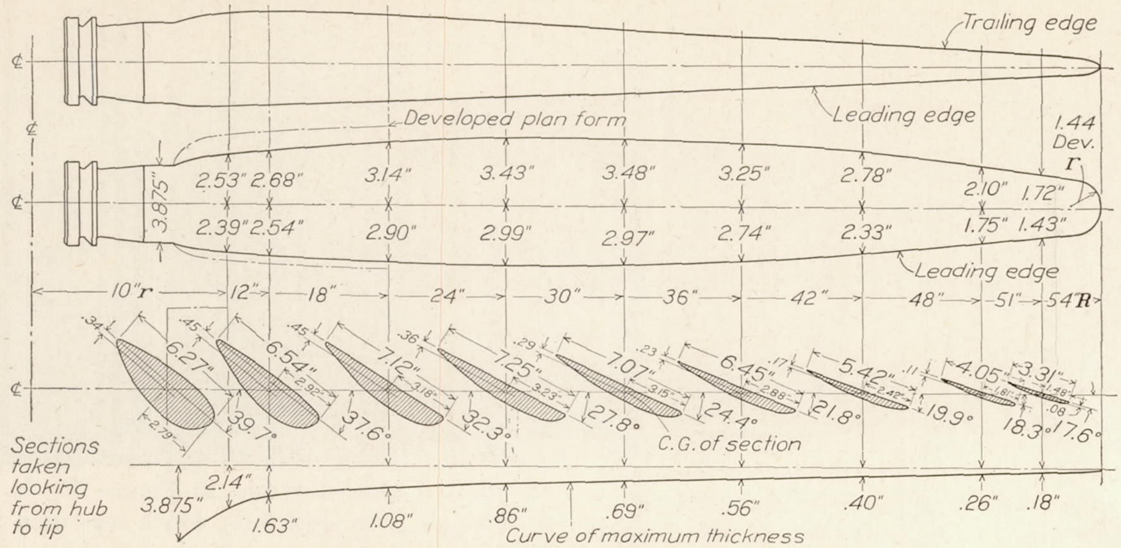

FIGURE 1. Metal blade 9.0-foot diameter propeller. Right-hand No. 4412

ORDINATES OF SECTIONS AT VARIOUS RADII FOR EXPERIMENTAL METAL PROPELLER BLADE

9.0 FEET DIAMETER, RIGHT-HAND (FIG. 1)

S	10″ r		12″ r		18″ r Upper	24″ r Upper	30″ r Upper	36″ r Upper	42″ r Upper	48″ r Upper	51″ r Upper
	Upper	Lower	Upper	Lower							
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
2. 5	0. 61	0. 25	0. 56	0. 11	0. 44	0. 35	0. 28	0. 23	0. 16	0. 11	0. 07
5	. 87	. 39	. 80	. 16	. 64	. 51	. 41	. 33	. 24	. 15	. 11
10	1. 17	. 52	1. 07	. 21	. 85	. 68	. 55	. 44	. 32	. 21	. 14
20	1. 41	. 63	1. 29	. 26	1. 03	. 82	. 66	. 53	. 38	. 25	. 17
30	1. 48	. 66	1. 36	. 27	1. 08	. 86	. 69	. 56	. 40	. 26	. 18
40	1. 47	. 65	1. 35	. 27	1. 07	. 85	. 68	. 56	. 40	. 26	. 18
50	1. 41	. 63	1. 29	. 26	1. 03	. 82	. 66	. 53	. 38	. 25	. 17
60	1. 29	. 57	1. 18	. 24	. 94	. 75	. 60	. 49	. 35	. 23	. 16
70	1. 10	. 49	1. 01	. 20	. 80	. 64	. 51	. 42	. 30	. 19	. 13
80	. 83	. 37	. 76	. 15	. 61	. 48	. 39	. 31	. 22	. 15	. 10
90	. 52	. 23	. 48	. 09	. 38	. 30	. 24	. 20	. 14	. 09	. 06
Rad. T. E.	0. 18		0. 14		. 08	. 07	. 05	. 04	. 03	. 02	. 02
Rad. L. E.	0. 64		0. 30		. 11	. 09	. 07	. 06	. 04	. 03	. 02
Chord	6. 27		6. 54		7. 12	7. 25	7. 07	6. 45	5. 42	4. 05	3. 31

The chord is divided into 10 equal parts, or stations, with the one at the leading edge subdivided into halves and quarters. S equals *stations in per cent of chord from the leading edge.*

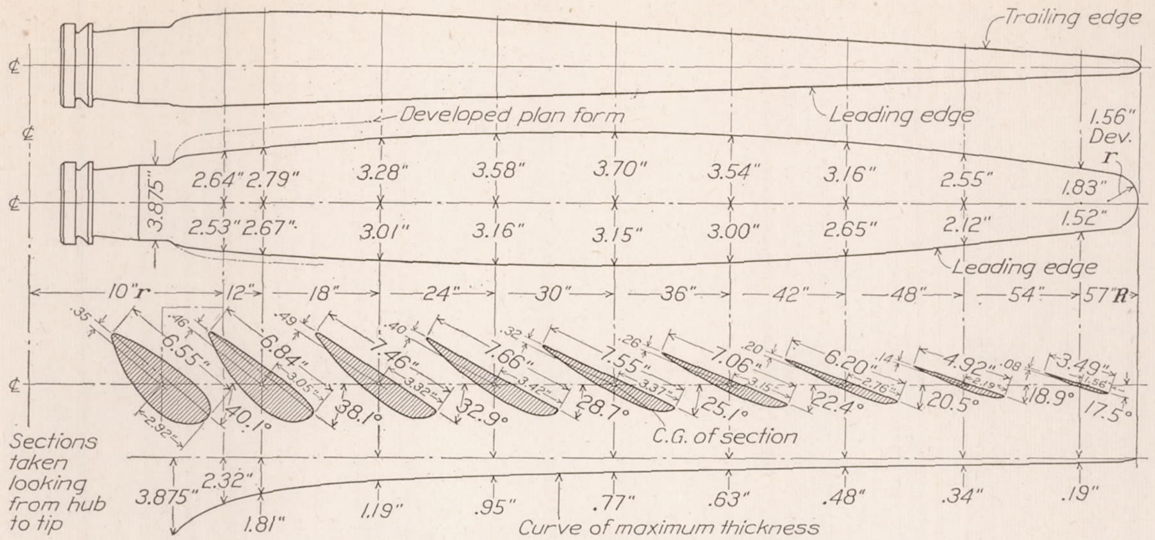

FIGURE 2.—Metal blade 9.5-foot diameter propeller. Right-hand No. 4413

ORDINATES OF SECTIONS AT VARIOUS RADII FOR EXPERIMENTAL METAL PROPELLER BLADE

9.5 FEET DIAMETER, RIGHT-HAND. (FIG. 2)

S	10″ r		12″ r		18″ r	24″ r	30″ r	36″ r	42″ r	48″ r	54″ r
	Upper	Lower	Upper	Lower	Upper	Upper	Upper	Upper	Upper	Upper	Upper
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
2.5	0.62	0.28	0.68	0.14	0.49	0.39	0.32	0.26	0.20	0.14	0.02
5	.84	.44	.86	.21	.70	.56	.46	.37	.28	.20	.08
10	1.13	.59	1.15	.28	.94	.75	.61	.50	.38	.27	.11
20	1.45	.70	1.39	.33	1.13	.90	.73	.60	.46	.32	.15
30	1.58	.74	1.46	.35	1.19	.95	.77	.63	.48	.34	.18
40	1.56	.73	1.45	.35	1.18	.94	.76	.62	.48	.34	.19
50	1.50	.70	1.39	.33	1.13	.90	.73	.60	.46	.32	.19
60	1.38	.64	1.27	.30	1.04	.83	.67	.56	.42	.30	.18
70	1.17	.55	1.08	.26	.88	.70	.57	.47	.36	.23	.17
80	.89	.42	.82	.20	.67	.53	.43	.35	.27	.19	.14
90	.55	.26	.51	.12	.42	.33	.27	.22	.17	.12	.11
Rad. T. E.	0.21		0.16		.09	.07	.06	.05	.04	.03	.07
Rad. L. E.	.72		.31		.12	.10	.08	.06	.05	.03	.01
Chord	6.55		6.84		7.46	7.66	7.55	7.06	6.20	4.92	3.49

The chord is divided into 10 equal parts, or stations, with the one at the leading edge subdivided into halves and quarters. S equals stations in per cent of chord from the leading edge.

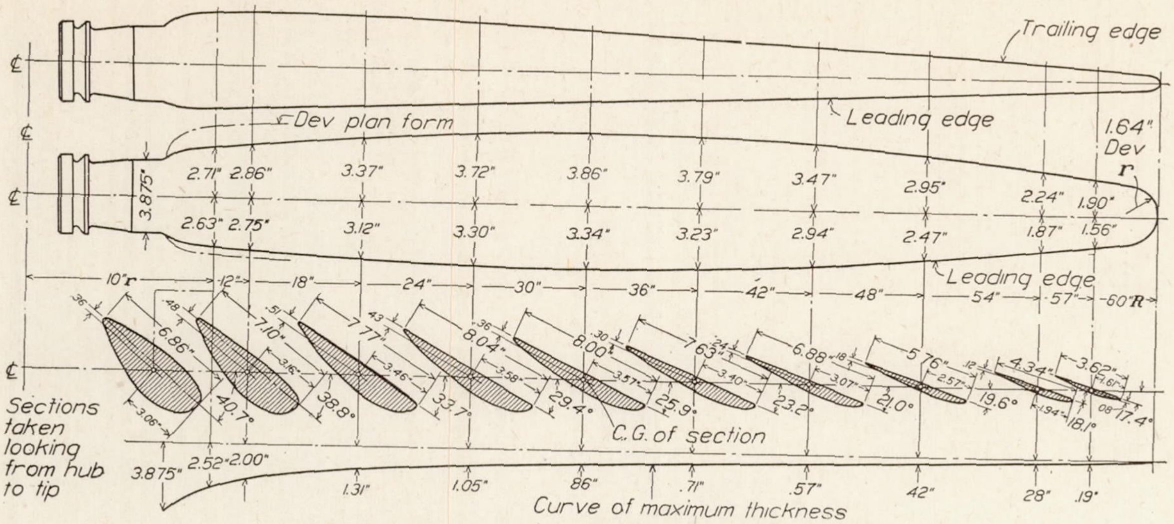

FIGURE 3.—Metal blade 10.0-foot diameter propeller. Right-hand No. 4414

ORDINATES OF SECTIONS AT VARIOUS RADII FOR EXPERIMENTAL METAL PROPELLER BLADE

10.0 FEET DIAMETER, RIGHT-HAND. (FIG. 3)

S	10″ r Upper	10″ r Lower	12″ r Upper	12″ r Lower	18″ r Upper	18″ r Lower	24″ r Upper	30″ r Upper	36″ r Upper	42″ r Upper	48″ r Upper	54″ r Upper	57″ r Upper
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
2.5	0.69	0.34	0.65	0.17	0.62	0.02	0.43	0.35	0.29	0.23	0.17	0.12	0.08
5	.95	.49	.93	.25	.75	.02	.62	.51	.42	.34	.25	.17	.11
10	1.23	.66	1.25	.33	.99	.03	.83	.68	.56	.45	.33	.22	.15
20	1.56	.79	1.50	.40	1.21	.04	1.00	.82	.68	.54	.40	.27	.18
30	1.69	.83	1.58	.42	1.27	.04	1.05	.86	.71	.57	.42	.28	.19
40	1.67	.82	1.57	.42	1.26	.04	1.04	.85	.70	.56	.42	.28	.19
50	1.61	.79	1.50	.40	1.21	.04	1.00	.82	.68	.54	.40	.27	.18
60	1.47	.72	1.38	.37	1.11	.035	.91	.75	.62	.50	.37	.25	.17
70	1.25	.62	1.17	.31	.94	.03	.78	.64	.53	.42	.31	.21	.14
80	.95	.47	.88	.24	.71	.02	.59	.48	.40	.32	.24	.16	.11
90	.57	.29	.55	.15	.44	.01	.37	.30	.25	.20	.15	.10	.07
Rad. T. E.	0.20		0.17		0.10		.08	.07	.06	.04	.03	.02	.02
Rad. L. E.	.79		.40		.14		.11	.09	.07	.06	.04	.03	.02
Chord	6.86		7.10		7.77		8.04	8.00	7.63	6.88	5.76	4.34	3.62

The chord is divided into 10 equal parts, or stations, with the one at the leading edge subdivided into halves and quarters. S equals stations in per cent of chord from the leading edge.

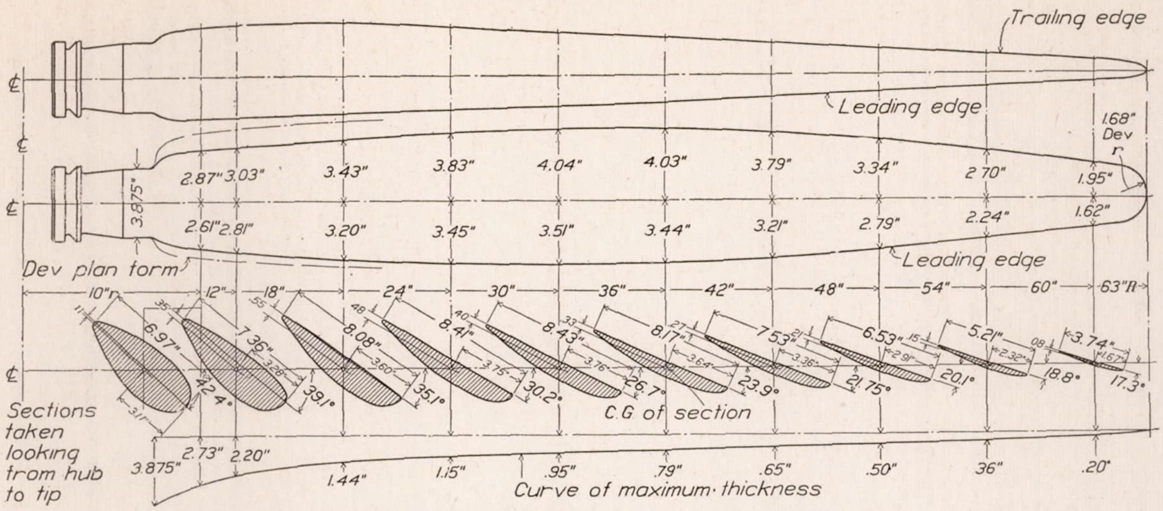

FIGURE 4.—Metal blade 10.5-foot diameter propeller. Right-hand No. 4102

ORDINATES OF SECTIONS AT VARIOUS RADII FOR EXPERIMENTAL METAL PROPELLER BLADE

10.5 FEET DIAMETER, RIGHT-HAND. (FIG. 4)

S	10″ *r*		12″ *r*		18″ *r*		24″ *r*	30″ *r*	36″ *r*	42″ *r*	48″ *r*	54″ *r*	60″ *r*
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Upper	Upper	Upper	Upper	Upper	Upper
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
2.5	0.56	0.50	0.62	0.28	0.57	0.03	0.47	0.39	0.32	0.27	0.21	0.15	0.08
5	.76	.73	.90	.40	.81	.04	.68	.56	.47	.38	.30	.21	.12
10	1.03	.97	1.20	.54	1.09	.05	.91	.75	.62	.51	.40	.28	.16
20	1.34	1.17	1.44	.65	1.31	.06	1.09	.90	.75	.62	.48	.34	.19
30	1.50	1.23	1.52	.68	1.38	.06	1.15	.95	.79	.65	.50	.36	.20
40	1.49	1.22	1.51	.67	1.37	.06	1.14	.94	.78	.64	.50	.36	.20
50	1.43	1.17	1.44	.65	1.31	.06	1.09	.90	.75	.62	.48	.34	.19
60	1.31	1.07	1.32	.59	1.20	.05	1.00	.83	.69	.57	.44	.31	.17
70	1.11	.91	1.13	.50	1.02	.045	.85	.70	.59	.48	.37	.27	.15
80	.84	.69	.85	.38	.77	.03	.64	.53	.44	.36	.28	.20	.11
90	.53	.43	.53	.24	.48	.02	.40	.33	.28	.23	.18	.13	.07
Rad. T. E.	0.27		0.20		0.11		.09	.07	.06	.05	.04	.03	.02
Rad. L. E.	1.00		.49		.16		.12	.10	.08	.07	.05	.04	.02
Chord	6.97		7.36		8.08		8.41	8.43	8.17	7.53	6.53	5.21	3.74

The chord is divided into 10 equal parts, or stations, with the one at the leading edge subdivided into halves and quarters. S equals stations in per cent of chord from the leading edge.

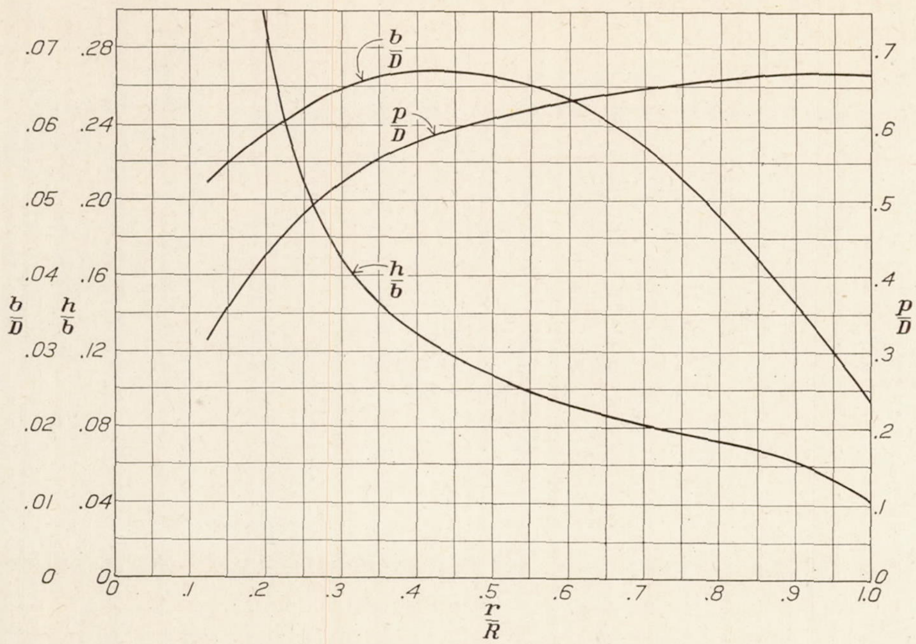

FIGURE 5.—Propeller blade form curves. D=diameter, p=pitch, b=blade width, h=blade thickness, r=radius, R=tip radius=$D/2$

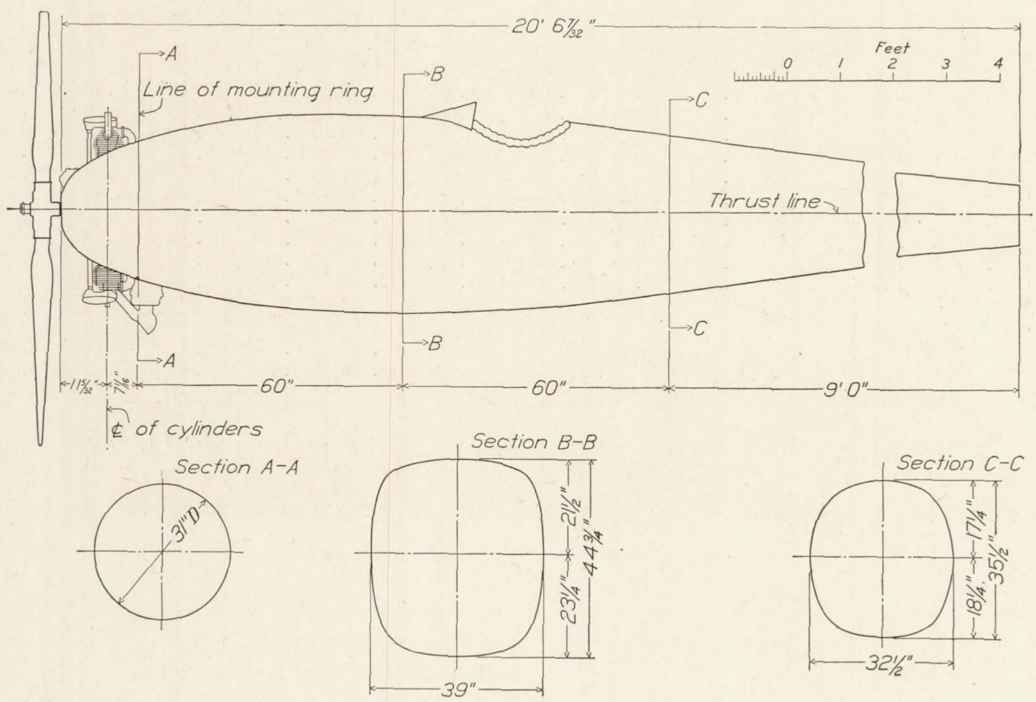

FIGURE 6.—Fuselage and engine

The resultant horizontal force of the propeller-body combination which may be either a thrust or a drag, was measured on the regular thrust balance. (Reference 1.) This resultant horizontal force R, may be thought of as composed of three horizontal components, such that

$$R = T - D - \Delta D$$

where

T = the thrust of the propeller while operating in front of the body (the tension in the crank shaft).

D = the drag of the airplane alone (without the propeller) at the same air velocity and density.

ΔD = the increase in drag of the airplane with propeller, due to the slip stream.

stream, and also the effect of the body interference on the propeller thrust and power.

RESULTS

The observed data points for each of the four propeller tests are given in Figures 9 to 12 and in Table I. They are reduced to the usual coefficients of thrust, power, and propulsive efficiency,

$$C_T = \frac{\text{effective thrust}}{\rho n^2 D^4}$$

$$C_P = \frac{\text{input power}}{\rho n^3 D^5}$$

$$\eta = \frac{\text{effective thrust} \times \text{velocity of advance}}{\text{input power}}$$

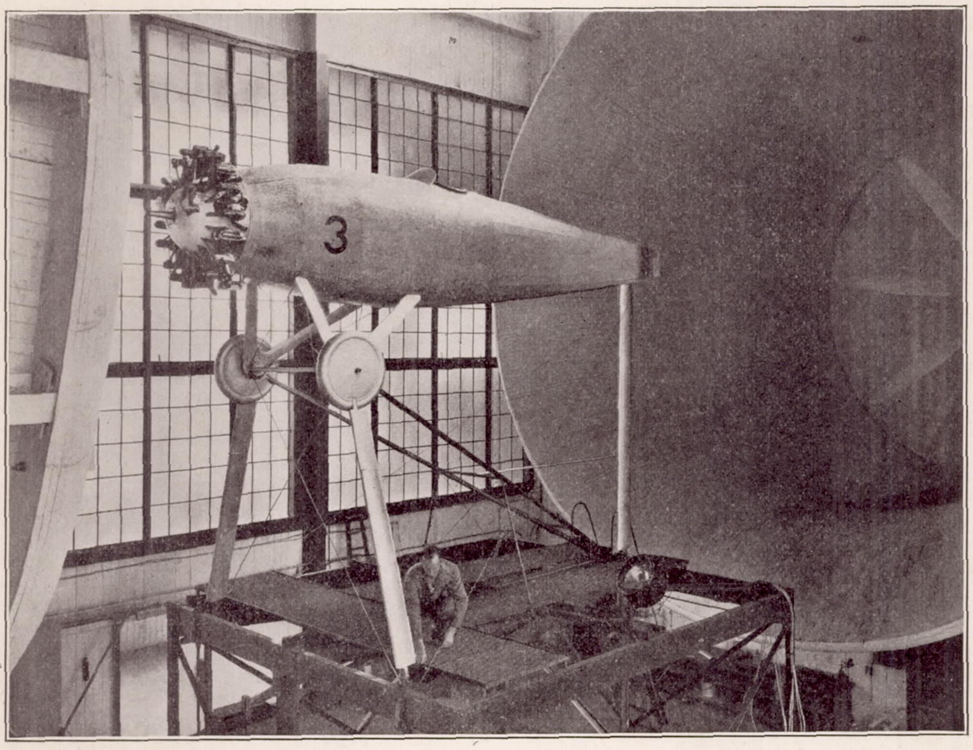

FIGURE 7.—Fuselage and engine mounted on propeller research tunnel balance

In order to obtain the propulsive efficiency, which includes the propeller-body interference, an effective thrust is used which is defined as

$$\begin{aligned}\text{Effective thrust} &= T - \Delta D \\ &= R + D.\end{aligned}$$

The propulsive efficiency, then, is the ratio of the useful power to the input power, or

$$\text{Propulsive efficiency} = \frac{\text{effective thrust} \times \text{velocity of advance}}{\text{input power}}.$$

This propulsive efficiency includes the increase in drag of all parts of the airplane affected by the slip stream, and also the effect of the body interference on the propeller thrust and power.

where D is the propeller diameter and n represents the revolutions per unit time. Since the coefficients are dimensionless, any homogeneous system of units may be used.

Figures 13, 14, and 15 give the thrust coefficient, power coefficient, and propulsive efficiency curves for all of the propellers for comparison. It will be noted that (1) the thrust coefficients throughout the working range show but little variation with all of the propellers, and the smaller the propeller the higher the thrust coefficient; (2) there was more difference between the power coefficients, and the smaller the propeller the higher the power coefficient; (3) the maximum propulsive efficiency increased slightly as the propeller diameter was increased.

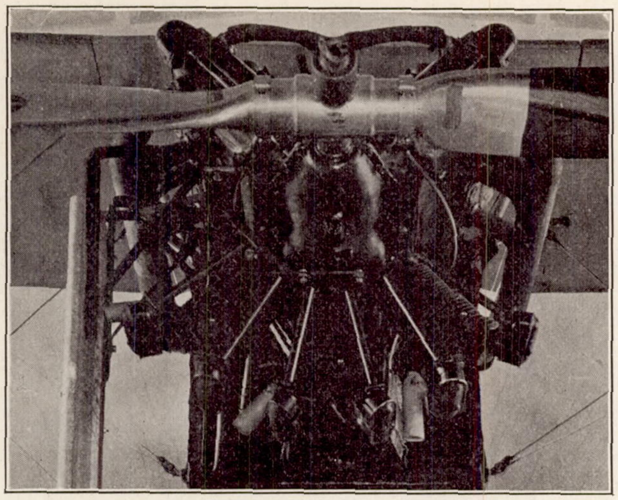

FIGURE 8.—J-5 cylinders mounted on E-2 engine for slip-stream torque tests

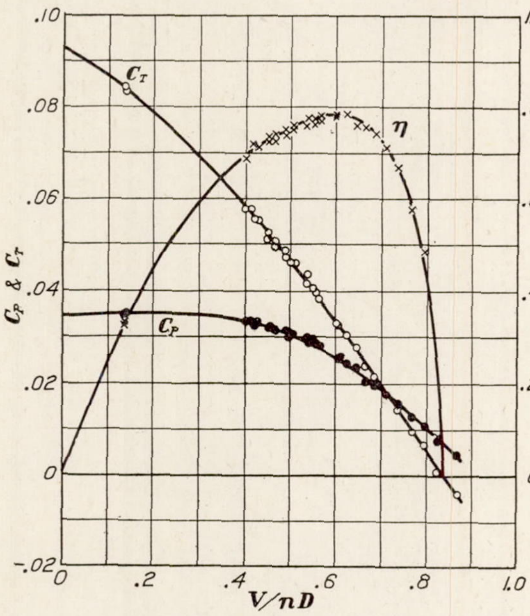

FIGURE 10.—Propeller No. 4413. Diameter 9 feet 5 inches

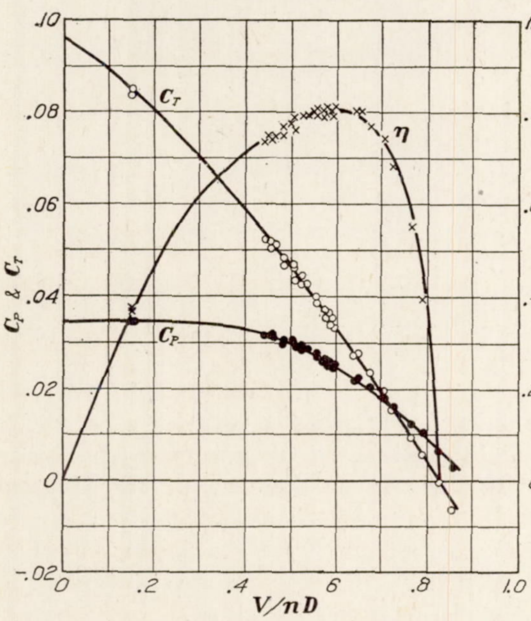

FIGURE 12.—Propeller No. 4102. Diameter 10 feet 5 inches

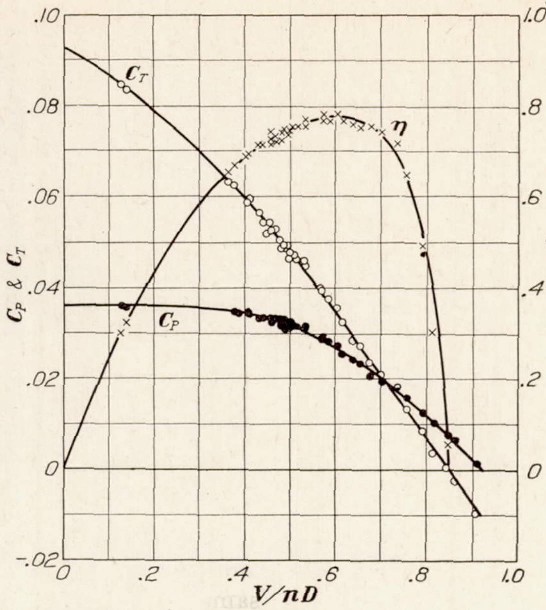

FIGURE 9.—Propeller No. 4412. Diameter 8 feet 11 inches

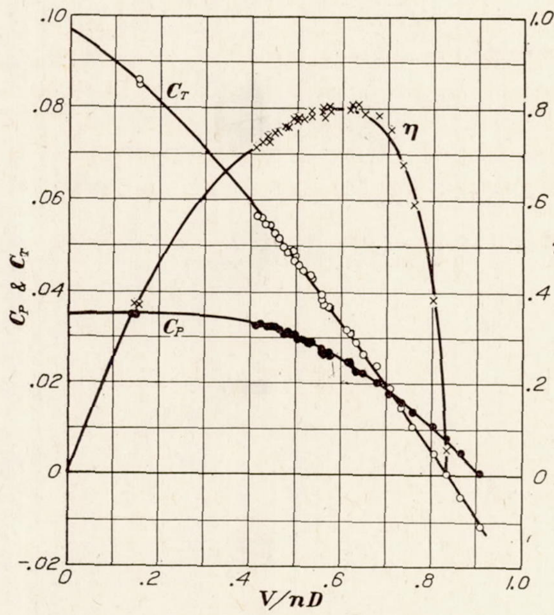

FIGURE 11.—Propeller No. 4414. Diameter 9 feet 11 inches

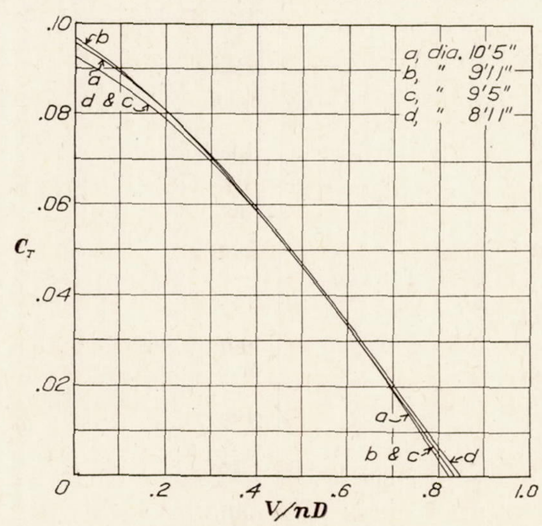

FIGURE 13.—Thrust coefficients

In Figure 16 the values of propulsive efficiency and $\frac{V}{nD}$ are plotted against the coefficient

$$C_S=\sqrt[5]{\frac{\rho V^5}{Pn^2}}$$

where V is the velocity of advance and P represents the power absorbed by the propeller. Propellers

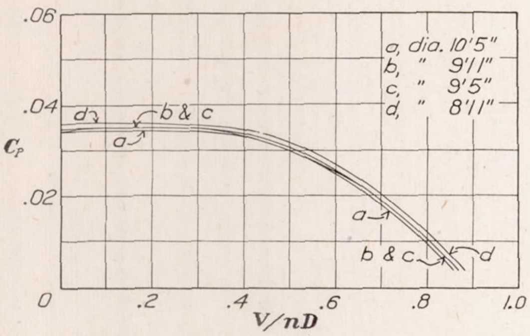

FIGURE 14.—Power coefficients

operating at the same value of C_S are fulfilling like requirements of power, velocity, and revolutions, and are, therefore, on a fair basis for comparison. Figure 16 shows that the larger propellers are more efficient throughout the entire flying range, and that within

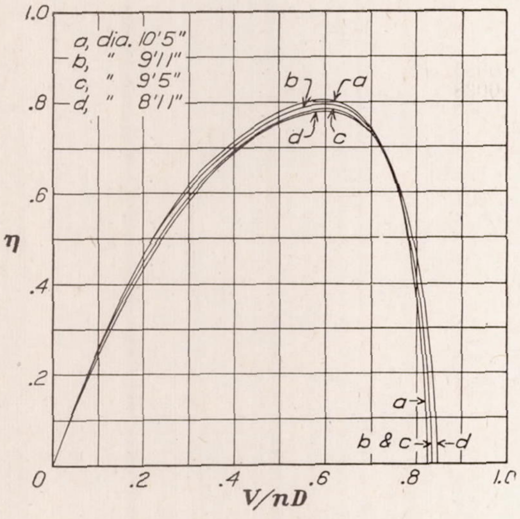

FIGURE 15.—Propulsive efficiencies

the range of the diameters tested, the increase in the efficiency is of the order of 1 per cent for each 10 per cent increase in the diameter. The curves of $\frac{V}{nD}$ vs. C_S are all very nearly the same up to the value of C_S for maximum efficiency, showing that the difference in power absorption due to body interference, again within the limits of the tests, has no appreciable effect on the diameter required to fit any given set of values of P, n, V, and ρ.

CONCLUSIONS

1. The difference in the aerodynamic coefficients found for the various diameter propellers was quite small.

2. Within the range of the tests, the propulsive efficiency was higher with the larger propellers, the

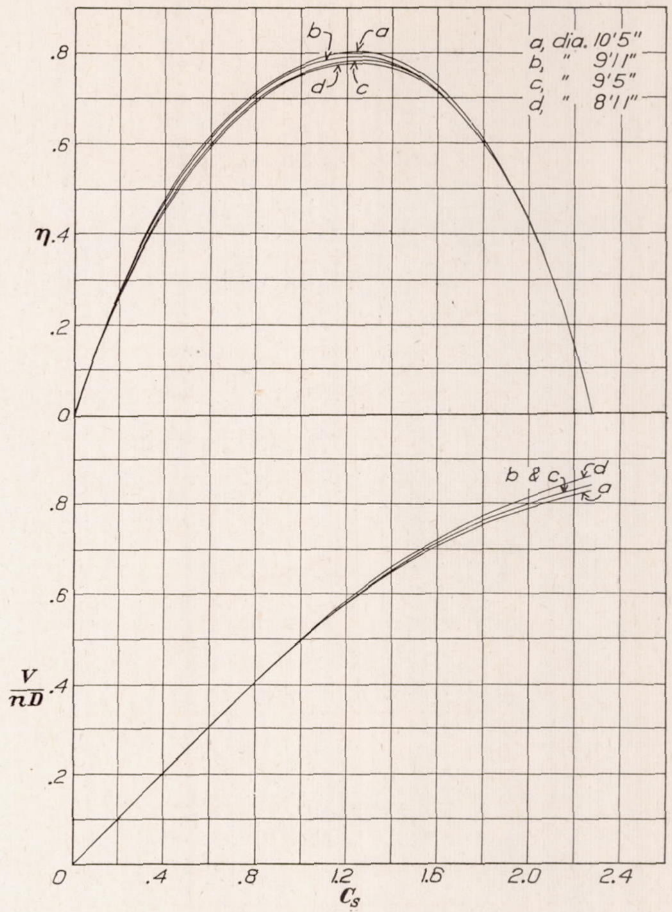

FIGURE 16.—$\frac{V}{n\ D}$ and η vs. C_S

difference in efficiency being of the order of 1 per cent for a 10 per cent change in diameter.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *March 12, 1929.*

REFERENCE

1. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. N. A. C. A. Technical Report No. 300, 1928.

TABLE I

OBSERVED DATA

Propeller No. 4412

Diameter, 8 feet 11 inches

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002288	82. 1	1, 750	579	646	0. 0525	0. 0332	0. 464	0. 734
. 002280	82. 5	1, 710	542	591	. 0505	. 0327	. 476	. 735
. 002280	82. 8	1, 705	524	562	. 0484	. 0318	. 479	. 729
. 002272	82. 9	1, 690	519	555	. 0488	. 0322	. 484	. 734
. 002272	83. 8	1, 680	513	551	. 0490	. 0322	. 492	. 749
. 002272	82. 8	1, 685	516	556	. 0494	. 0322	. 485	. 744
. 002272	83. 5	1, 690	516	559	. 0492	. 0320	. 488	. 750
. 002269	88. 3	1, 750	550	582	. 0476	. 0318	. 498	. 746
. 002269	88. 0	1, 750	545	572	. 0469	. 0314	. 496	. 740
. 002269	90. 8	1, 765	561	586	. 0474	. 0319	. 509	. 755
. 002262	91. 1	1, 760	555	575	. 0468	. 0317	. 511	. 755
. 002259	94. 2	1, 750	547	558	. 0460	. 0318	. 531	. 770
. 002259	94. 2	1, 750	541	554	. 0452	. 0315	. 531	. 763
. 002256	104. 4	1, 810	529	511	. 0394	. 0290	. 570	. 775
. 002256	104. 1	1, 805	528	514	. 0398	. 0290	. 570	. 782
. 002256	103. 5	1, 750	485	457	. 0378	. 0282	. 584	. 769
. 002256	103. 5	1, 700	444	409	. 0358	. 0274	. 601	. 785
. 002256	103. 1	1, 650	396	350	. 0324	. 0260	. 616	. 769
. 002256	103. 0	1, 595	344	291	. 0289	. 0241	. 639	. 765
. 002248	102. 7	1, 550	318	261	. 0274	. 0236	. 653	. 758
. 002248	102. 4	1, 500	265	210	. 0236	. 0210	. 675	. 758
. 002248	103. 1	1, 455	233	175	. 0210	. 0196	. 700	. 748
. 002248	103. 5	1, 390	200	138	. 0181	. 0185	. 735	. 720
. 002248	103. 4	1, 355	165	100	. 0138	. 0160	. 754	. 650
. 002248	103. 1	1, 290	119	56	. 0085	. 0127	. 790	. 495
. 002248	102. 4	1, 240	87	23	. 0038	. 0101	. 815	. 306
. 002248	102. 8	1, 200	63	3	. 0005	. 0078	. 845	. 057
. 002248	102. 5	1, 100	7	−47	−. 0098	. 0010	. 920	---------
. 002248	102. 5	1, 175	49	−11	−. 0020	. 0063	. 861	---------
. 002258	80. 6	1, 760	579	666	. 0545	. 0332	. 453	. 744
. 002249	81. 5	1, 750	566	637	. 0525	. 0330	. 459	. 730
. 002252	78. 9	1, 705	538	599	. 0521	. 0330	. 456	. 720
. 002252	78. 9	1, 705	536	601	. 0524	. 0328	. 456	. 729
. 002252	74. 3	1, 705	549	645	. 0561	. 0336	. 430	. 719
. 002252	75. 7	1, 700	542	621	. 0545	. 0334	. 440	. 719
. 002255	68. 5	1, 675	540	655	. 0591	. 0344	. 404	. 695
. 002255	68. 2	1, 670	535	649	. 0589	. 0342	. 403	. 694
. 002255	61. 2	1, 660	541	688	. 0632	. 0350	. 364	. 656
. 002255	62. 8	1, 645	533	666	. 0624	. 0350	. 377	. 670
. 002264	20. 8	1, 600	519	859	. 0845	. 0360	. 128	. 302
. 002264	22. 2	1, 590	511	838	. 0834	. 0358	. 138	. 321

TABLE I—Continued

Propeller No. 4413

Diameter, 9 feet 5 inches

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002249	85. 5	1, 495	491	475	0. 0433	0. 0298	0. 535	0. 776
. 002249	86. 2	1, 505	489	464	. 0416	. 0293	. 535	. 760
. 002249	88. 8	1, 510	492	458	. 0409	. 0293	. 550	. 768
. 002249	88. 9	1, 510	490	454	. 0405	. 0292	. 550	. 764
. 002246	90. 5	1, 530	492	457	. 0398	. 0285	. 553	. 772
. 002246	90. 6	1, 530	488	450	. 0392	. 0284	. 554	. 765
. 002238	93. 7	1, 560	497	461	. 0389	. 0280	. 562	. 780
. 002238	93. 7	1, 560	497	458	. 0386	. 0280	. 562	. 775
. 002235	104. 9	1, 620	481	416	. 0324	. 0251	. 605	. 780
. 002235	104. 0	1, 610	478	416	. 0329	. 0252	. 603	. 786
. 002235	104. 0	1, 560	429	363	. 0306	. 0242	. 623	. 787
. 002235	103. 2	1, 500	384	303	. 0276	. 0234	. 644	. 760
. 002235	103. 2	1, 450	316	241	. 0235	. 0206	. 665	. 759
. 002235	102. 7	1, 400	279	201	. 0211	. 0194	. 685	. 741
. 002235	102. 7	1, 350	233	156	. 0175	. 0175	. 710	. 712
. 002228	102. 6	1, 300	191	116	. 0141	. 0155	. 737	. 760
. 002228	102. 4	1, 245	146	73	. 0096	. 0129	. 769	. 577
. 002228	102. 0	1, 200	115	46	. 0065	. 0109	. 795	. 484
. 002228	101. 5	1, 150	73	5	. 0007	. 0075	. 825	. 084
. 002228	101. 2	1, 090	36	−26	−. 0044	. 0041	. 869	----
. 002234	82. 1	1, 530	521	526	. 0460	. 0304	. 502	. 759
. 002234	82. 4	1, 525	517	519	. 0456	. 0304	. 505	. 758
. 002236	78. 7	1, 505	517	533	. 0481	. 0313	. 489	. 750
. 002236	78. 8	1, 505	515	521	. 0471	. 0312	. 490	. 740
. 002236	74. 5	1, 500	517	551	. 0503	. 0315	. 464	. 740
. 002236	74. 5	1, 500	515	541	. 0494	. 0314	. 464	. 729
. 002239	71. 1	1, 475	508	546	. 0516	. 0319	. 451	. 730
. 002239	70. 4	1, 460	500	544	. 0524	. 0320	. 451	. 739
. 002239	66. 6	1, 450	507	566	. 0551	. 0330	. 429	. 716
. 002239	65. 6	1, 450	503	567	. 0551	. 0327	. 423	. 714
. 002239	64. 3	1, 450	513	594	. 0578	. 0333	. 415	. 720
. 002239	62. 0	1, 440	507	581	. 0575	. 0336	. 402	. 689
. 002248	20. 20	1, 400	499	808	. 0840	. 0344	. 135	. 330
. 002248	20. 38	1, 390	493	792	. 0835	. 0346	. 137	. 330

TABLE I—Continued

Propeller No. 4414

Diameter, 9 feet 11 inches

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002225	85. 0	1, 420	551	522	0. 0433	0. 0289	0. 531	0. 795
. 002225	85. 3	1, 410	542	500	. 0420	. 0288	. 536	. 781
. 002225	88. 6	1, 410	519	467	. 0392	. 0276	. 559	. 794
. 002225	88. 6	1, 410	513	461	. 0388	. 0273	. 559	. 795
. 002223	90. 3	1, 435	522	469	. 0380	. 0269	. 559	. 790
. 002223	90. 8	1, 435	515	454	. 0368	. 0265	. 561	. 780
. 002223	93. 8	1, 450	518	455	. 0362	. 0260	. 574	. 800
. 002223	93. 4	1, 435	512	452	. 0366	. 0264	. 576	. 799
. 002219	105. 0	1, 500	519	424	. 0317	. 0246	. 621	. 801
. 002219	104. 1	1, 495	515	419	. 0316	. 0245	. 619	. 799
. 002219	104. 1	1, 455	452	363	. 0289	. 0227	. 635	. 809
. 002212	103. 6	1, 415	415	319	. 0268	. 0221	. 650	. 789
. 002212	103. 3	1, 350	354	259	. 0238	. 0207	. 680	. 782
. 002212	103. 0	1, 290	277	186	. 0188	. 0177	. 709	. 750
. 002212	103. 3	1, 250	230	134	. 0144	. 0157	. 734	. 675
. 002212	102. 9	1, 200	177	87	. 0102	. 0131	. 760	. 590
. 002212	102. 6	1, 135	127	38	. 0049	. 0105	. 803	. 380
. 002212	102. 8	1, 095	92	3	. 0004	. 0081	. 834	. 051
. 002212	102. 2	1, 050	49	−32	−. 0048	. 0047	. 865	----
. 002212	102. 4	1, 000	3	−67	−. 0112	. 0003	. 910	----
. 002217	82. 4	1, 440	581	560	. 0454	. 0298	. 507	. 771
. 002217	82. 8	1, 430	568	544	. 0446	. 0296	. 514	. 775
. 002221	77. 8	1, 400	568	564	. 0482	. 0306	. 493	. 776
. 002221	78. 8	1, 400	560	546	. 0466	. 0303	. 499	. 768
. 002221	73. 6	1, 380	553	561	. 0493	. 0308	. 474	. 759
. 002221	74. 2	1, 370	547	545	. 0486	. 0310	. 481	. 755
. 002224	69. 5	1, 350	554	573	. 0524	. 0321	. 456	. 744
. 002224	70. 1	1, 350	547	561	. 0515	. 0318	. 461	. 746
. 002224	62. 4	1, 330	547	593	. 0561	. 0327	. 416	. 714
. 002224	63. 0	1, 315	539	579	. 0560	. 0330	. 425	. 721
. 002224	66. 1	1, 335	549	577	. 0541	. 0326	. 440	. 730
. 002224	65. 8	1, 330	542	572	. 0541	. 0324	. 439	. 734
. 002233	21. 2	1, 260	519	812	. 0855	. 0346	. 1500	. 370
. 002233	21. 2	1, 250	519	797	. 0850	. 0350	. 1512	. 368

TABLE I—Continued

Propeller No. 4102

Diameter, 10 feet 5 inches

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002224	85. 2	1, 295	555	484	0. 0397	0. 0274	0. 556	0. 806
. 002224	85. 2	1, 290	543	464	. 0383	. 0270	. 558	. 791
. 002224	88. 0	1, 295	529	450	. 0369	. 0261	. 575	. 811
. 002224	87. 8	1, 295	525	444	. 0364	. 0260	. 573	. 804
. 002224	89. 6	1, 305	535	444	. 0358	. 0260	. 580	. 800
. 002224	90. 0	1, 300	529	440	. 0358	. 0260	. 585	. 806
. 002220	93. 2	1, 320	528	434	. 0343	. 0252	. 596	. 811
. 002220	92. 4	1, 320	523	425	. 0336	. 0249	. 591	. 797
. 002217	105. 1	1, 370	501	373	. 0275	. 0223	. 650	. 802
. 002217	104. 5	1, 370	497	372	. 0274	. 0220	. 645	. 805
. 002217	104. 5	1, 310	418	288	. 0232	. 0203	. 675	. 771
. 002209	104. 1	1, 245	341	217	. 0194	. 0183	. 706	. 745
. 002209	103. 6	1, 205	279	159	. 0151	. 0160	. 725	. 683
. 002209	102. 9	1, 140	196	86	. 0091	. 0126	. 762	. 555
. 002209	102. 9	1, 100	148	45	. 0051	. 0102	. 790	. 398
. 002209	102. 5	1, 050	88	−5	−. 0006	. 0066	. 825	----
. 002209	102. 1	1, 010	32	−46	−. 0062	. 0026	. 855	----
. 002218	81. 6	1, 315	590	535	. 0427	. 0284	. 525	. 790
. 002218	82. 2	1, 295	576	515	. 0425	. 0286	. 536	. 796
. 002218	77. 4	1, 280	571	518	. 0437	. 0291	. 510	. 766
. 002218	77. 8	1, 250	555	505	. 0447	. 0296	. 526	. 795
. 002223	73. 3	1, 235	559	523	. 0470	. 0304	. 501	. 775
. 002223	73. 8	1, 230	549	511	. 0464	. 0300	. 507	. 785
. 002223	70. 9	1, 230	554	530	. 0480	. 0303	. 486	. 770
. 002223	70. 4	1, 230	547	515	. 0466	. 0299	. 484	. 754
. 002223	65. 6	1, 195	545	531	. 0511	. 0317	. 465	. 749
. 002223	65. 2	1, 195	539	523	. 0504	. 0313	. 461	. 741
. 002225	62. 6	1, 185	534	533	. 0521	. 0314	. 446	. 740
. 002225	63. 2	1, 180	529	527	. 0519	. 0314	. 454	. 750
. 002230	19. 0	1, 060	472	696	. 0850	. 0347	. 152	. 372
. 002230	19. 0	1, 060	468	690	. 0841	. 0344	. 152	. 372

TABLE II

FINAL ADJUSTED COEFFICIENTS

Propeller No. 4412

Diameter, 8 feet 11 inches

$\frac{V}{nD}$	C_T	C_P	η	C_S
0. 10	0. 0864	0. 0360	0. 240	0. 194
. 15	. 0829	. 0360	. 346	. 292
. 20	. 0789	. 0360	. 438	. 389
. 25	. 0746	. 0360	. 518	. 486
. 30	. 0698	. 0359	. 582	. 584
. 35	. 0649	. 0352	. 645	. 682
. 40	. 0591	. 0342	. 690	. 785
. 45	. 0539	. 0335	. 723	. 886
. 50	. 0478	. 0318	. 751	. 996
. 55	. 0412	. 0294	. 770	1. 112
. 60	. 0360	. 0270	. 778	1. 232
. 65	. 0279	. 0236	. 770	1. 376
. 70	. 0210	. 0199	. 739	1. 531
. 75	. 0140	. 0160	. 656	1. 711
. 80	. 0070	. 0119	. 471	1. 941

TABLE II—Continued

Propeller No. 4413

Diameter, 9 feet 5 inches

$\frac{V}{nD}$	C_T	C_P	η	C_S
0. 10	0. 0867	0. 0348	0. 250	0. 195
. 15	. 0829	. 0350	. 355	. 294
. 20	. 0788	. 0350	. 450	. 392
. 25	. 0740	. 0350	. 528	. 489
. 30	. 0690	. 0348	. 595	. 586
. 35	. 0639	. 0342	. 653	. 688
. 40	. 0582	. 0335	. 695	. 789
. 45	. 0522	. 0323	. 726	. 893
. 50	. 0466	. 0308	. 756	1. 002
. 55	. 0400	. 0282	. 778	1. 122
. 60	. 0330	. 0252	. 785	1. 252
. 65	. 0266	. 0222	. 778	1. 391
. 70	. 0196	. 0188	. 730	1. 549
. 75	. 0126	. 0149	. 634	1. 740
. 80	. 0055	. 0103	. 427	2. 000

TABLE II—Continued

Propeller No. 4102

Diameter, 10 feet 5 inches

$\frac{V}{nD}$	C_T	C_P	η	C_S
0. 10	0. 0890	0. 0345	0. 258	0. 196
. 15	. 0850	. 0344	. 370	. 294
. 20	. 0805	. 0342	. 470	. 393
. 25	. 0758	. 0340	. 556	. 492
. 30	. 0701	. 0340	. 619	. 591
. 35	. 0646	. 0338	. 670	. 690
. 40	. 0588	. 0330	. 712	. 790
. 45	. 0527	. 0317	. 748	. 896
. 50	. 0465	. 0299	. 778	1. 008
. 55	. 0400	. 0275	. 799	1. 128
. 60	. 0332	. 0247	. 806	1. 257
. 65	. 0263	. 0216	. 791	1. 394
. 70	. 0191	. 0180	. 743	1. 563
. 75	. 0118	. 0138	. 640	1. 765
. 80	. 0042	. 0091	. 370	2. 050

TABLE II—Continued

Propeller No. 4414

Diameter, 9 feet 11 inches

$\frac{V}{nD}$	C_T	C_P	η	C_S
0. 10	0. 0896	0. 0350	0. 256	0. 195
. 15	. 0857	. 0350	. 368	. 293
. 20	. 0809	. 0350	. 461	. 390
. 25	. 0760	. 0349	. 545	. 489
. 30	. 0708	. 0346	. 614	. 588
. 35	. 0650	. 0341	. 667	. 688
. 40	. 0590	. 0343	. 709	. 786
. 45	. 0530	. 0321	. 743	. 895
. 50	. 0465	. 0302	. 770	1. 005
. 55	. 0400	. 0279	. 789	1. 126
. 60	. 0331	. 0250	. 795	1. 255
. 65	. 0266	. 0220	. 785	1. 391
. 70	. 0196	. 0185	. 740	1. 557
. 75	. 0127	. 0148	. 645	1. 740
. 80	. 0056	. 0105	. 425	1. 990

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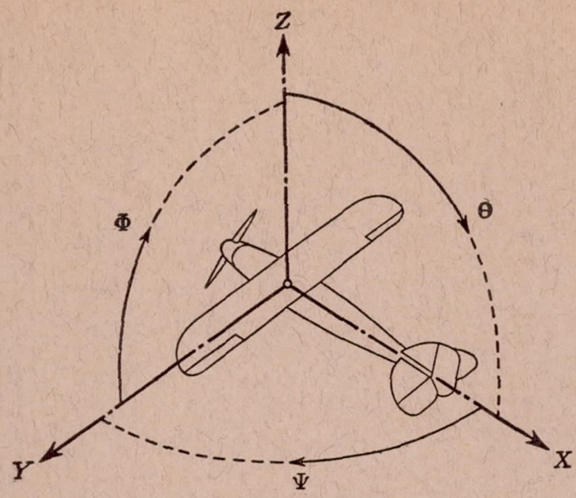

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L = \frac{L}{qbS} \qquad C_M = \frac{M}{qcS} \qquad C_N = \frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch.
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute, r. p. m.
Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft
1 m = 3.2808333 ft.